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Predictive Analysis of Global Solar Radiation in Awka Using Statistical Error Indicators

Nwokoye, A. O. C; Mbadugha, A. O

Department of Physics and Industrial Physics, Nnamdi Azikiwe University, Awka, Nigeria

ABSTRACT

Information on the accessibility of solar radiation at a location is an imperative factor in choosing appropriate solar energy system and devices for several applications. Sunshine hours, rainfall, cloud cover, atmospheric pressure data measured in Awka (06.20°N, 07.00°E), Anambra state for a period of nine (2005– 2013) were used to create Angstrom-type regression equations (models) for estimating the global solar radiation received on a horizontal surface in Awka. The results of the correlation were also tested for error using statistical test methods of the mean bias error, MBE, root mean square error, RMSE, and mean percentage error, MPE, to calculate the performance of the models. It was perceived that combination of parameters could be used to estimate the total solar radiation incident on a location.

KEYWORDS: *Sunshine, Solar, radiation, Rainfall, solar energy*

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INTRODUCTION

Solar energy is one of the most ancient sources of energy; it is the elementary element for all fossil and renewable energies. Solar energy is obviously highly available and could be easily harnessed to reduce the level of confidence on hydrocarbon - based energy (Innocent, 2015).

Solar radiation although is available on the entire earth surface, nevertheless the quantity of radiation being received varied based on the geographical expanse, relief, atmospheric conditions and seasons of the year.

Hence it is necessarily relevant to know the quantity and the variation of accessible solar radiation for a definite time duration.

The best way to discern the amount of solar radiation at any location is to fix sensitive measuring systems at many locations in the required region and monitor their day - to-day recording and maintenance, (Gana *et al.*,2014). Therefore, it is crucial to develop a model to predict the global solar radiation on the basis of the statistical error indicators. The statistical error indicators used include Root Mean Square Error (RMSE),Mean Bias Error (MBE), Mean Percentage Error (MPE), Correlation Coefficient (CC), and Coefficient of Determination (R).The meteorological data for Awka used in this study were obtained from Nigerian Meteorological Agency (NIMET).

METHODOLOGY

Numerous climatic parameters have been used in developing empirical relations for predicting the monthly mean global solar radiation (Medugu *et al.*, 2013).Among the prevailing correlations; the data of sunshine duration are most extensively obtainable in many locations and a number of sunshine based formulas have been proposed to determine solar radiation.

The utmost mostly used method was developed by Angstrom and later modified by Prescott. The Angstrom – Prescott formula given by (Duffiie and Beckman,1994) as:

$$\frac{\bar{H}}{\bar{H}_O} = a + b\left(\frac{\bar{s}}{\bar{s}_O}\right) \qquad (1)$$

Where $\bar{H}$ and$\bar{H}_O$ are respectively the mean global solar radiation ($\mathrm{MJ}m^{-2}day^{-1}$) and the monthly mean extra terrestrial global solar radiation on a horizontal surface in ($\mathrm{MJ}m^{-2}day^{-1}$).

$\bar{S}$and $\bar{S}_o$ are the monthly mean number of sunshine hours measured in hours and the monthly mean maximum daily sunshine duration or day length respectively (hours).The a and b are regression constants to be determined.

The monthly mean extra – terrestrial global solar radiation was calculated from the following equation

$$\bar{H}_o = \frac{24 \times 3600}{\pi} I_{SC}\left[1 + 0.033COS\frac{360}{365}\right] \times \left[\frac{\pi}{180}\omega_S Sin\square sin\delta\right] \qquad (2)$$

where I_{SC} = $1367^{W}/_{m^2}$ is the solar constant. The n is the Julian day number starting from January 1 to December 31. $\emptyset$ is the latitude angle of the location ($\emptyset$ = 6.2°), δ is the declination angle while ω_S sunset hour angle.

The δ and ω_S were calculated from these formular (Innocent *et al.,* 2015).

$$\delta = 23.45 \sin\left[360\left(\frac{284+n}{365}\right)\right] \quad (3)$$

$$\omega_S = \cos^{-1}[-\tan\phi\tan\delta] \quad (4)$$

The maximum possible sunshine duration $\bar{S}_o$ was calculated using the following equation ( )

$$\bar{S}_o = \frac{2}{15}\omega_s \quad (5)$$

The regression constants a and b were determined using a statistical software programme, IBM SPSS 21.

STATISTICALTEST INDICATOR METHODS

In literature, quite a lot of statistical test methods had been used to determine the performance of the models of solar radiation estimation. These comprise Root Mean Square Error (RMSE), Mean Bias Error (MBE), Mean Percentage Error (MPE), Correlation Coefficient (R), and Coefficient of Determination (R^2).

Root Mean Square Error (RMSE), the RMSE is the frequency used measure of the different between the values of the predicted by a model and the values actually measured. It is always positive and low. RMSE may be calculated from the following equation, (Akpabio and Etuk, 2013):

$$RMSE = \left[\sum\left(\bar{H}_{ipred} - \bar{H}_{imeas}\right)^2/n\right]^{``} \quad (6)$$

Mean Bias Error (MBE), MBE provides information on the long term performance of the models. The ideal value of the MBE is zero. A positive and a negative value of MBE indicate the average amount of over estimation and under estimation. It was recommended that a zero value for MBE is ideal,(Iqbal,1983). The MBE is given by

$$MBE = \left[\sum\left(\bar{H}_{ipred} - \bar{H}_{imeas}\right)\right]/n \quad (7)$$

Mean Percentage Error (MPE), the MPE test provides information on long term performance of the examined regression equations. A positive and a negative value of MPE indicate the average amount of over estimation and under estimation in the predicted values respectively. A low MPE is desirable (Okonkwo and Nwokoye, 2014).

The MPE may be computed from the following equation:

$$MPE = \frac{\left[\sum\frac{(\bar{H}_{imeas} - \bar{H}_{ipred})}{\bar{H}_{imeas}}\right]}{n} \times 100 \quad (8)$$

where $\bar{H}_{ipred}$ and $\bar{H}_{imeas}$ are the ith predicted and measured values respectively of solar radiation, n is the total number of observations.

Coefficient of determination(R^2), this is the ratio of explained variation,$(\bar{H}_{pred} - \bar{H}_m)^2$, to the total variation $(\bar{H}_M - H_M)^2$, $\bar{H}_m$ is the mean of the observed H values. The ratio lies between zero and one. A high value of (R^2) is desirable (Falayi and Rabiu, 2012).

RESULTS AND DISCUSSION

It is known from table 1 that the correlation coefficient, R is within the range of 0.599 to 0.948 which specifies that a good fit exists between the measured global solar radiation, H_m and the predicted global solar radiation, H_p for some of the models excluding models 7, 10, 15, 16, 17 and 18.

Based on the correlation coefficient, R and coefficient of determination, R^2, models 11 and 13 produce the highest value thereby ranked first in terms of R and R^2 and model 17 the least.

For Mean Bias Error (MBE), models 3, 14, 15, and 18 indicate slightly underestimation in their predicted values and models 10, 17 and specify overestimation in their predicted values..

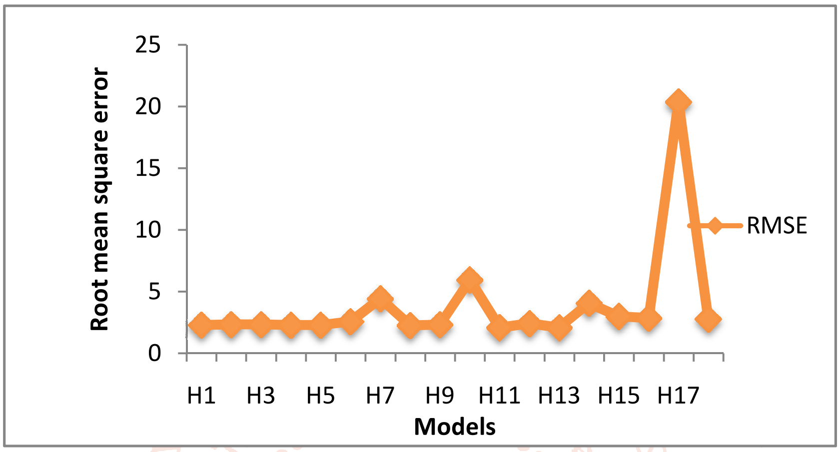
Considering the Mean Percentage Error (MPE), nearly all the models specified underestimation excluding models 14, 15, 16 and 18 that indicated overestimation in their predicted values.

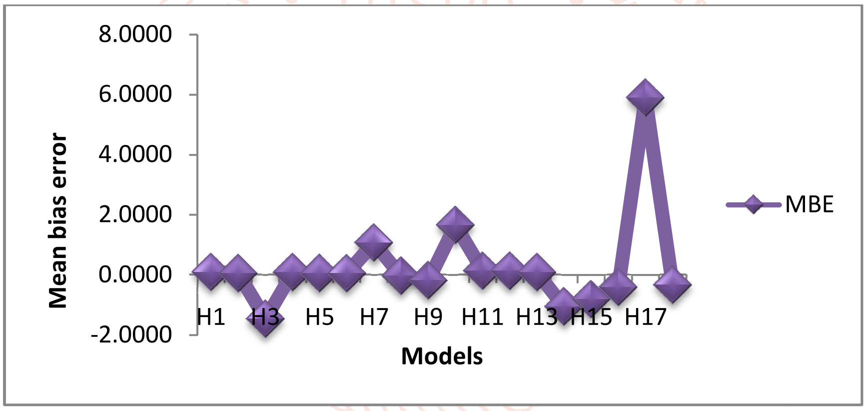
Explanations of the models showed that model 13 when compared to the other models, displayed the lowest RMSE, with low MBE and MPE. This makes it most appropriate for estimating global solar radiation for Awka. These statistical errors were summarized in figures 1-3 below;

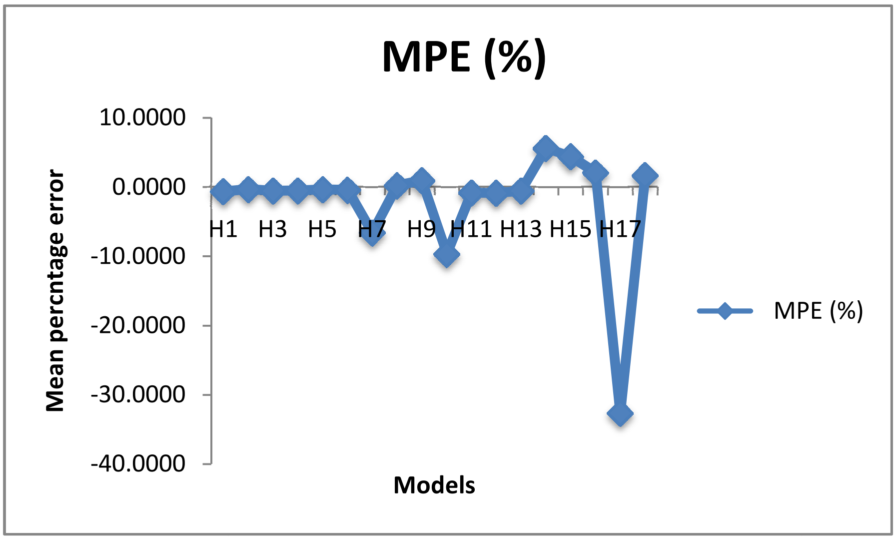
Table 1: Statistical Error Indicators of the Models.

Model	MBE	RMSE	MPE	R	R^2
$\frac{H_m}{H_o} = a + b\,(\bar{n}/\bar{N})$	0.0801	2.2936	-0.6343	0.7740	0.5990
$\frac{H_m}{H_o} = a + b\,(\bar{n}/\bar{N})^{-1}$	0.0450	2.3377	-0.3328	0.8120	0.6593
$\frac{H_m}{H_o} = a + b\,4(\bar{n}/\bar{N}) - c\,(\bar{n}/\bar{N})^2$	-1.4696	2.3312	-0.5507	0.8160	0.6659
$\frac{H_m}{H_o} = a + b\,(\bar{n}/\bar{N}) - c\,(\bar{n}/\bar{N})^2 + d\,(\bar{n}/\bar{N})^3$	0.0769	2.2813	-0.5245	0.8170	0.6675
$\frac{H_m}{H_o} = a\,(\bar{n}/\bar{N})\ b$	0.04431	2.2875	0.3625	0.8040	0.6464
$\frac{H_m}{H_o} = a + b\,(\overline{RF})$	0.0439	2.5700	-0.4250	0.8500	0.7230
$\frac{H_m}{H_o} = a + b\log(\overline{RF})$	1.0648	4.4301	-6.5980	0.7240	0.5240
$\frac{H_m}{H_o} = a + b\,(\overline{RF}) - c\,(\overline{RF})^2$	-0.0409	2.2575	0.2167	0.8960	0.8030
$\frac{H_m}{H_o} = a + b\,(\bar{c}/C) + c\,(\overline{RF})$	-0.1899	2.3248	0.9216	0.9300	0.8640
$\frac{H_m}{H_o} = a + b\,(\bar{n}/\bar{N}) + c\,(\overline{RF})$	1.6480	5.9520	-9.6857	0.9350	0.8740
$\frac{H_m}{H_o} = a + b\,(\overline{RF}) + c\,(\overline{W}) + d\,(\bar{A})$	0.1270	2.0872	-0.8169	0.9480	0.8890

$\frac{\overline{H_m}}{\overline{H_o}} = a + b\,(\overline{n}/\overline{N}) + c\,(\overline{W})$	0.1219	2.4210	-0.8643	0.8800	0.7750
$\frac{\overline{H_m}}{\overline{H_o}} = a + b\,(\overline{n}/\overline{N}) + c\,(\overline{RF}) + d(\overline{W})$	0.0776	2.0853	-0.5403	0.9480	0.8990
$\frac{\overline{H_m}}{\overline{H_o}} = a + b\,(\overline{n}/\overline{N}) + c\,(\overline{c}/C)$	-1.0629	4.0553	5.6003	0.9100	0.8290
$\frac{\overline{H_m}}{\overline{H_o}} = a + b\,(\overline{n}/\overline{N}) + c\,(\overline{c}/C) + d\,\overline{RF})$	- 0.8187	3.0002	4.3945	0.9350	0.8740
$\frac{\overline{H_m}}{\overline{H_o}} = a + b(\overline{n}/\overline{N}) + c\,(\overline{A}) + d\,(\overline{W})$	-0.4159	2.8612	2.0695	0.9120	0.8320
$\frac{\overline{H_m}}{\overline{H_o}} = a + b(\overline{n}/\overline{N}) + c\,(\overline{c}/C) + (\overline{A})$	5.8828	20.3788	-32.6524	0.9280	0.8620
$\frac{\overline{H_m}}{\overline{H_o}} = a + b\,\overline{n}/\overline{N}) + c\,(\overline{A})$	-0.3456	2.7849	1.6799	0.9120	0.8320







CONCLUSION

Thus computer statistical software program, (IBM SPSS 21) was used in obtaining the regression constants. The accuracy of the estimated values was tested by calculating the Mean Bias Error (MBE), Root Mean Square Error (RMSE), and Mean Percentage Error (MPE).

From the comparison of the results of these models, it was observed that the predicted values were in good agreement with the measured and the models were slightly similar.

Model 13 based on the correlation coefficient, R of 0.9480, coefficient of determination, R^2 of 0.8990, Mean Bias Error of 0.0775, Mean Percentage Error of -0.5403 the least Root Mean Square Error of 2.0853 and with the regression equation given as:

$$\frac{\overline{H}_m}{\overline{H}_o} = 0.663 + 0.008\,(\overline{n}/\overline{N}) - 0.016\,(\overline{RF}) - 0.010(\overline{w})$$

is the best performed model, hence can be used for predicting solar radiation for Awka.